

148

Get DRA

FACILITY FORM 602

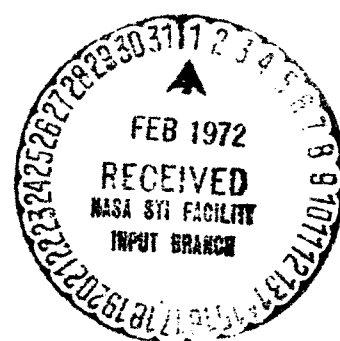
N73-12920  
(ACCESSION NUMBER)

37  
(PAGES)

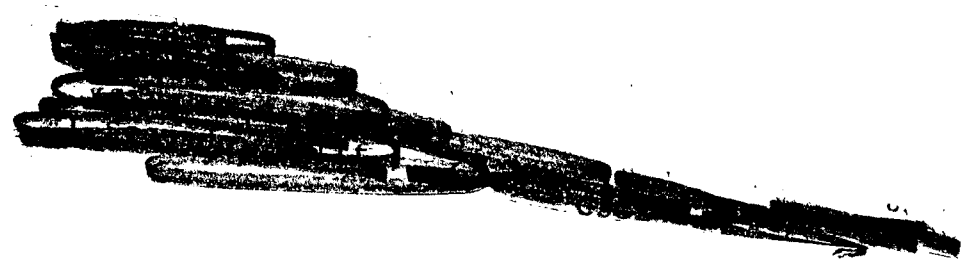
NASA-CR-125905  
(NASA CR OR TMX OR AD NUMBER)

G-3  
(THRU)  
(CODE)

31  
(CATEGORY)



THE AEROSPACE CORPORATION



Report No. ATR-72(7235)-3  
MECHANICAL/STRUCTURAL DESIGN  
IMPLICATIONS OF SPACE-BASING ON  
SHUTTLE SYSTEM

Prepared by  
K. G. Ludlow  
Applied Mechanics Division  
Engineering Science Operations

71 SEP 27

Systems Engineering Operations  
THE AEROSPACE CORPORATION  
El Segundo, California

Prepared for  
Office of Manned Space Flight  
NASA HEADQUARTERS  
Washington, D. C.

Contract No. NASW-2129

PRECEDING PAGE BLANK NOT FILMED

Report No.  
ATR- 72(7235)-3

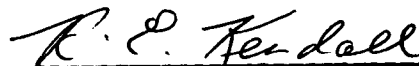
MECHANICAL/STRUCTURAL DESIGN IMPLICATIONS  
OF SPACE-BASING ON SHUTTLE SYSTEM

Approved by



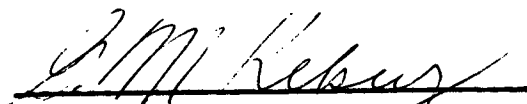
E. R. Ryder, Manager  
Design Section  
Vehicle Systems Dept.

Approved by



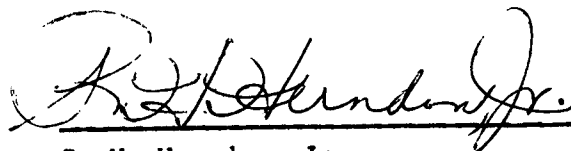
R. E. Kendall  
NASA Task B Director  
Advanced Vehicle Systems Directorate  
Systems Planning Division

Approved by



G. M. Kelsey, Head  
Vehicle Systems Dept.  
Applied Mechanics Division

Approved by



R. H. Herndon, Jr.  
Director Launch Systems Office  
Advanced Vehicle Systems Directorate  
Systems Planning Division

## ABSTRACT

A conceptual design study has been conducted to identify some of the mechanical/structural differences which result from the use of a tug/payload combination in a space-basing mode as contrasted with a ground-based mode of operation. The basic mechanical/structural differences associated with space-basing were identified by analyzing a space-basing strategy in which the tug and payload are launched separately by the EOS and comparing it with the ground-based mode in which the tug/payload is launched as an integral unit in the EOS. This operational concept, which is the simplest of a number of possible space-basing strategies, was also used to identify the major impacts on the Earth Orbit Shuttle (EOS).

An investigation of on-orbit payload deployment/retrieval mechanisms that could be utilized in the EOS for both the space-basing and ground-basing modes of operation was also conducted as a part of this study in conjunction with The Aerospace Corporation DOD impact studies performed for SAMSO.

The mechanical/structural differences that were identified from a comparison of payloads operating in the ground and space-based modes of operation are discussed in addition to delineating the advantages and disadvantages associated with various payload deployment/retrieval mechanisms.

## TABLE OF CONTENTS

I.	INTRODUCTION . . . . .	1
II.	STUDY OBJECTIVES . . . . .	1
III.	GROUND-BASING DEFINITION . . . . .	2
IV.	SPACE-BASING DEFINITION . . . . .	2
V.	EXPANDED CONCEPT OF SPACE-BASING . . . . .	3
VI.	STUDY APPROACH . . . . .	3
VII.	GROUND RULES AND ASSUMPTIONS . . . . .	4
VIII.	PAYLOAD DEPLOYMENT/RETRIEVAL CONCEPTS . . . . .	5
	A. Description and Characteristics of Deployment/ Retrieval Concepts . . . . .	5
	B. Concept Comparison Criteria . . . . .	8
IX.	COMPARISON BETWEEN GROUND AND SPACE-BASING CONCEPTS . . .	12
X.	IMPACT OF EXPANDED STRATEGIES ON GROUND-BASED VEHICLE SYSTEM . . . . .	14
	A. Extended Mission Capability . . . . .	14
	B. Operational Requirements . . . . .	14
	C. General Comments . . . . .	15
XI.	CONCLUSIONS . . . . .	16

## FIGURES

Figure 1	Ground-Based Strategy
Figure 2	Space-Based Strategy
Figure 3	Space-Basing Analysis, Representative Space-Basing Strategies
Figure 4	Space-Basing Analysis, Vehicle System Implications
Figure 5	Space-Basing Analysis, Programmatic Implications
Figure 6	Linkage Deployment/Retrieval Concepts
Figure 7	Forward Pivot Deployment/Retrieval Concepts
Figure 8	Teleoperator Deployment/Retrieval Concepts
Figure 9	Payload Bay Door Deployment/Retrieval Concepts
Figure 10	Combined Deployment/Retrieval Concepts
Figure 11	Deployment/Retrieval Mechanism Selection Guide
Figure 12	EOS Payload Bay Arrangement
Figure 13	Typical Tug-to-EOS Docking Arrangement

## I. INTRODUCTION

Results are presented of a conceptual design study that was conducted to identify the major mechanical/structural differences which result from the use of a tug/payload combination in a space-basing mode as contrasted with a ground-based mode of operation. Space-basing of a tug/payload combination, although it can be accomplished in a number of ways, differs from the ground-basing mode of operation in that the tug can be based in space while awaiting the arrival of the payload in the Earth Orbit Shuttle (EOS), in the simplest mode, and can be refueled in space in some of the more elaborate modes. The ground-basing mode, in which the tug and payload are launched as a unit in the EOS, is adequate for many or most of the DOD missions but many of the contemplated NASA missions could utilize to advantage the concept of space-basing because of the characteristics of the various contemplated missions. Therefore, a study was made of the space-basing operation to determine the more significant mechanical/structural characteristics of the interface between the tug and payload, the tug/EOS, and the payload/EOS. The basic mechanical/structural characteristics associated with space-basing and the major impacts on critical elements of the system were identified by analyzing the simplest of several possible space-basing strategies while recognizing that the more sophisticated strategies will result in additional differences in both the mechanical/structural design and the interface requirements.

An investigation of deployment/retrieval mechanisms that could be used in the EOS for the space-basing and ground-basing modes of operation was also conducted as a part of this study in conjunction with the DOD impact studies performed for SAMSO. An evaluation of concepts proposed by contractors and other concepts derived from Aerospace in-house studies is also presented in this report.

## II. STUDY OBJECTIVES

The objective of the study was to identify the more significant differences between ground-based and space-based tug/payload combinations with respect to the structural/mechanical requirements and configurational characteristics, particularly in the areas of structural and mechanical interfaces, docking

mechanisms, etc. A further objective was to identify the impact on the tug/payload and EOS resulting from the structural/mechanical requirements of space-basing with respect to the structural supports, electrical and fluid interface requirements, clearance and access provisions, etc.

### III. GROUND-BASING DEFINITION

In the ground-basing mode, the tug/payload combination is launched from the ground in the Earth-to-Orbit Shuttle (EOS) as shown schematically in Figure 1. The tug/payload combination is then deployed and separated from the EOS in low earth orbit using a suitable deployment mechanism, followed by transfer of the payload to the desired orbit by the tug. The tug then returns to low altitude orbit for transport to earth via the EOS. After being refueled and checked-out, as required, on the ground, the tug is returned to the low orbit by the EOS and hence to the mission orbit where the tug recovers the payload, and returns it to the low earth orbit. The combined tug/payload is returned to earth via the EOS.

### IV. SPACE-BASING DEFINITION

In the simplest postulated space-basing mode, the tug and payload are launched separately as shown in Sketches A1 and B1 shown in Figure 2. Subsequently, the tug and payload are prepared for deployment as shown in Sketches A2 and B2 (Figure 2). Two postulated alternative methods of mating the tug and payload are shown in Sketches A3 and B3 (Figure 2). Sketch A3 depicts the EOS as the active maneuvering element during the orbital mating of the payload, attached to the EOS, and the tug; Sketch B3 depicts the tug as the active maneuvering element for mating with the payload after it is deployed from the EOS. Using the EOS as the active maneuvering element appears to be the more likely approach since the availability of the crew would greatly simplify the docking operation. After the tug and payload are docked together, the combined tug and payload are separated from the shuttle to perform a mission similar to that described for the ground-based payload.

## V. EXPANDED CONCEPT OF SPACE-BASING

Space-basing, as defined above (Section IV), describes the space-basing mode of operation in its simpler form. Other representative space-basing strategies, described below, are outlined in Figures 3, 4 and 5. In Figure 3, the space-basing mode analyzed in this report is identified by the symbol GB.

The strategies shown in Figures 3, 4 and 5 expand the basic space-basing concept described in Section IV by: a.) postulating the extension of mission durations, b.) by increasing the  $\Delta V$  capabilities of the tug through the utilization of the entire shuttle payload bay capacity for the tug alone, and c.) by providing an orbital propellant depot (OPD) for refueling and/or storage of the tug. These strategies are indicated in Figure 3 by the symbols GB-X, SB, and SB/OPD, respectively. These expanded strategies, and the strategy in which one tug is used for both operational modes (GB/SB) were investigated only briefly in this study.

## VI. STUDY APPROACH

The study to identify the major mechanical/structural differences which result from the use of a tug/payload combination in a space-basing mode as contrasted with a ground-based mode of operation was essentially conducted in three separate parts. The first part of the study involved a comparative evaluation of payload deployment/retrieval mechanisms. This part of the study was conducted in conjunction with The Aerospace Corporation DOD impact study since the tug/payload combination defined for this study (Section VII) is typical in many respects to the DOD payloads under consideration. The second part of the study consisted of a comparison between a ground-based tug/payload combination operating in a ground-based mode and the same tug/payload combination operating in a space-based mode. This relatively unsophisticated space-based strategy was used to determine the basic mechanical/structural characteristics of the interface between the tug and payload, the tug/EOS and the payload/EOS. The third part of the study involved a brief analysis of the remaining (expanded) space-based strategies to determine the more significant differences between the ground and space-based operational modes.



## VII. GROUND RULES AND ASSUMPTIONS

The ground rules and assumptions used in this study are as follows:

1. The McDonnell Douglas Corporation (MDAC) EOS orbiter payload bay geometry and structural attachments were selected as a representative baseline arrangement. The payload bay characteristics of the MDAC EOS orbiter are as follows:

- a. Payload clear volume                      15 ft dia x 60 ft long
- b. Payload bay compartment length      65.75 ft
- c. Static clearances between payload clear volume diameter and adjacent orbiter structure:
  1. At bottom of payload                      0.25 ft (3.0 in.)
  2. At horizontal centerline                  0.417 ft (5.0 in.)
- d. Distance between forward bulkhead and payload      3.83 ft<sup>1</sup> (46.0 in.)
- e. Docking mechanism hinge point - 5.0 in. aft of the forward bulkhead and 81.0 in. above the payload centerline

2. The representative tug and payload selected as baseline for study purposes is a tug having the dimensions noted below combined with a scaled-up version of the Tracking Data Relay Satellite (TDRS) having dimensional characteristics as follows:

### a. Tug

<u>Dimensions</u>	<u>Ft</u>	<u>Weight (Lb)</u>
Overall length	36.25 <sup>2</sup>	66,558 (fully loaded with propellant)
Diameter	15.0	

### b. Scaled-up TDRS

Overall length	21.0	7,950
Diameter	15.0	

---

<sup>1</sup> Dimension established by MDAC as the interface plane for docking payloads.

<sup>2</sup> Dimension with the Pratt & Whitney RL-10 derivative engine skirt retracted thus reducing the on-orbit engine length by 60.0 inches.

# VIII. PAYLOAD DEPLOYMENT/RETRIEVAL CONCEPTS

A number of deployment/retrieval concepts for a typical tug/payload have been tentatively defined. These concepts are shown in Figures 6 to 10, respectively. The forward pivot deployment/retrieval concept, depicted by MDAC and shown in Figure 7, and the MDAC orbiter and tie-down system were selected for use in comparing ground-based and space-based deployment/retrieval requirements. The basic characteristics of the various deployment/retrieval concepts, in addition to the advantages and disadvantages associated with each of the respective mechanisms, are discussed below under the appropriate headings.

## A. Description and Characteristics of Deployment/Retrieval Concepts

### 1. Linkages

All concepts shown in Figure 6 are dual linkage arrangements in which one or several linkages, depending on the concept and deployment geometry, is positioned on each side of the payload.

<u>Concept Description</u>	<u>Advantages</u>	<u>Disadvantages</u>
4-Bar Linkage and Scissor Linkage	<ul style="list-style-type: none"> <li>a. Fabrication simplicity.</li> <li>b. Fine adjustments easily achieved.</li> </ul>	<ul style="list-style-type: none"> <li>a. Fixed in-orbit deployed position.</li> <li>b. Unsuitable for multiple payload arrangements.</li> <li>c. Payload clearance envelope exceeded locally due to linkage geometry (EOS impact).</li> <li>d. Synchronized motion required between arms.</li> <li>e. Pitch plane movement only.</li> <li>f. Deployment questionable if one side of linkage fails.</li> </ul>
Swing Link	<ul style="list-style-type: none"> <li>a. Provides additional inplane payload movement.</li> <li>b. Minimum radial clearance requirements.</li> </ul>	<ul style="list-style-type: none"> <li>a. Unsuitable for multiple payload arrangements.</li> <li>b. Lack of torsional stiffness in yaw.</li> <li>c. Deployment questionable if one side fails.</li> </ul>

All of the linkage concepts require accurate alignment and precise joint motion synchronization to prevent variations in the deployment motion which could cause the payload to wedge between the linkage assembly.

## 2. Forward Pivot

The forward pivot mechanism shown in Figure 7 utilizes a hinge located at the forward face of the EOS payload bay. Half of the hinge is attached to the EOS; the other half is attached to a docking device which in turn is attached to the payload. The payload is rotated out of the EOS payload bay about the forward pivot.

### Advantages

- a. Simple, straightforward pivot hinge design.
- b. Stable control of deployment due to the wide displacement of the hinge arms.
- c. Crew transfer capability easily incorporated.
- d. Fewer actuators required in comparison, for example, to linkage concepts.
- e. Pivot concept can be adapted to either end of payload bay.

### Disadvantages

- a. Fixed in-orbit deployed position.
- b. Unsuitable for multiple payload arrangement.
- c. Limited to single degree of freedom (inplane).

The forward pivot mechanism is a simple straightforward approach. However, the payload is restricted to being deployed in a single rotation plane. A disadvantage associated with this concept is the inverted position of the tug during launch in which, as contrasted with the conventional launch arrangement (nozzle aft), the acceleration forces on the fluid propellant are in opposite, instead of the same direction, during launch and orbital flight. A cursory evaluation of the respective plumbing arrangements indicates that additional plumbing lines, valves and fittings are required for the inverted arrangement. The overall effect of the inverted position of the tug is an increase in the tug mass fraction.

## 3. Teleoperator

The teleoperator concept defined in Figure 8 is basically a crane or derrick mechanism comprised of several connected links driven independently at the joints.

Advantages

- a. Deployed payload can be maneuvered to obtain a two degree of freedom motion capability.
- b. Adaptable to alternative locations in payload bay.
- c. Teleoperator end fitting can be adapted to suit different manipulator devices.
- d. Considerable practical experience available with ground applications of teleoperators used for removal/replacement of isotopes and orthotic devices for amputees.

Disadvantages

- a. Lack of stiffness due to limited space and inherent flexibility of cantilever structures. Relatively slow deployment to minimize deflections of structure.

The teleoperator is particularly well suited to multiple payload deployment. The device can also adjust or vary the deployed position of the payload.

4. Payload Bay Door

The payload bay door concept shown in Figure 9 uses the door as a primary structural element to which the payload is attached during launch. In orbit, the payload is rotated by the door to the proper position for deployment.

Advantages

- a. Payload can be positioned to clear EOS in one simple operation.

Disadvantages

- a. Weight penalty associated with strengthening doors to support payload.
- b. Requirement for several separate doors to accommodate multiple payload arrangements would involve an even greater weight penalty.
- c. Connection of electrical power, fuel, and command and sensor line umbilicals may be severe problem (15" fuel line) assuming that these connections must be rotated to the deployed position.

The payload bay door concept is a novel approach. However, deployment of the payload from inside the EOS payload bay to a position outside, and

adjacent to, the vehicle fuselage by rotating the door does not appear to provide sufficient advantages to overcome the probable structural weight penalty associated with this concept. This concept is, however, attractive enough to warrant further consideration.

### 5. Combined Concepts

Several combined concepts are shown in Figure 10 - the crane (teleoperator) and banjo pivot, crane and segmented structural door, and a crane combined with a complete structural door. These combinations were selected as being representative of combined concepts having sufficient potential to be considered as attractive deployment/retrieval candidates. The relative advantages and disadvantages of these combined concepts are associated with the merits previously identified for the individual concept used in the combination approach. By combining two or possibly three separate deployment concepts into one, it is possible in some combinations to obtain a composite of the advantages associated with the individual concepts.

### B. Concept Comparison Criteria

An effort was made to rank the various contractor payload deployment/retrieval concepts as well as those concepts developed in-house during the study. To assist in ranking the various mechanisms, the selection parameters listed in the matrix shown in Figure 11 were derived. These parameters are the more significant ones to be considered when selecting a deployment/retrieval mechanism. The deployment/retrieval concepts are ranked according to their capability with respect to a given parameter. It is difficult at this time to select a specific concept as the best overall since payload design data and operational characteristics are not known in sufficient detail. The concept ultimately selected will depend on the emphasis placed on specific characteristics; for example, maintainability and reliability may be more important in some cases than light weight.

### 1. System Weight Impact

System weight impact (Figure 11) refers to the relative weight increase of the shuttle/payload system imposed by the addition of the payload deployment/retrieval mechanism system. The five categories of deployment mechanisms are ranked in the order of lowest (1) to highest (9) weight based on an overall assessment and comparison of the size and number of required structural members, links, mechanisms and fittings, etc.

### 2. Operational Reliability

On-orbit operational reliability (Figure 11) refers to the degree of reliability that can be achieved with each particular mechanism relative to the other systems. The five categories of deployment/retrieval mechanisms are ranked in the order of highest (1) to lowest (5) on-orbit reliability based on relative assessment of the number, type and overall characteristics of the drives and mechanisms required to operate the devices.

### 3. Power Requirements

Each concept is ranked on the basis of the lowest (1) to highest (4) estimated power required to operate each particular mechanism during the deployment/retrieval cycle as compared to each of the other concepts considered.

### 4. Thermal Distortion Effects

Thermal distortions may be induced in the mechanism due to changes in temperature in the mechanism resulting from proximity to the tug's cryogenic tank, payload bay environmental changes, and on-orbit sun/shade variations from ambient conditions. Some mechanisms are more sensitive to temperature variations than others particularly where the mechanism is comprised of relatively long linkage members, for example. As indicated in Figure 12, the static clearances between the payload envelope and shuttle payload bay are marginal at best and any significant decrease in clearances resulting from mechanism thermal distortions could present a problem. The five categories of deployment/retrieval mechanisms are ranked in the order of lowest (1) to highest (5) effect on the mechanism due to thermal gradients.

#### 5. Mechanism Complexity

The complexity associated with each particular mechanism can be qualitatively assessed by evaluating the number of linkages, pivots, drives and joints that are used. In addition, the number and complexity of the adjustments required to attain the proper alignment is important in assessing mechanism simplicity. Some mechanisms, particularly those that can be more easily aligned than others, use fewer links, pivots, drives and fittings, etc. The five categories of deployment mechanisms are ranked in the order of lowest (1) to greatest (5) complexity.

#### 6. Adaptability to P/L Mix

Each deployment/retrieval mechanism is ranked with respect to the degree of adaptability associated with the deployment of different types and numbers of payloads without the requirement for excessive adjustments or modifications. The payloads may vary from a single payload, that uses the complete payload volume, to a multi-payload arrangement consisting of a number of spacecraft, or mixes thereof. The five categories of deployment mechanisms are ranked in the order of greatest (1) to lowest (6) adaptability with respect to the deployment of a variety of payloads.

#### 7. Tug Impact

The impact to the tug that results from installing or attaching the deployment/retrieval mechanism to the tug is assessed under this heading. For example, additional structural members may be required in the tug to resist local load concentrations that occur because of the type of mechanism that is used to deploy the payload. The five categories of deployment mechanisms are ranked in the order of lowest (1) to highest (6) impact on the tug vehicle.

#### 8. Mechanism Check-out and Adjustment Accessibility

The various deployment/retrieval mechanisms are ranked according to the access provisions that are required in the EOS vehicle to install, check-out and adjust the payload deployment/retrieval

mechanism. The five categories of deployment mechanisms are ranked in the order of highest (1) to lowest (5) accessibility for check-out and adjustment without the requirement for special access provisions.

#### 9. Concept Evaluation

Based on a summary comparison of the concepts considered in this study, it appears that the fixed linkage mechanism concepts described previously contain sufficient inherent disadvantages to detract from the attractiveness of this deployment/retrieval device as a candidate for further consideration. The main disadvantage of the linkage concepts is the lack of lateral stiffness provided during payload deployment. Lateral stiffness is difficult to achieve since insufficient clearance exists between the EOS payload bay and the tug/payload for providing sufficiently stiff structural members. The linkage concepts also require accurate alignment of the joints and precise synchronization of the joint motion to prevent wedging of the payload between the linkage assembly during deployment.

The payload bay door concept for payload deployment is a novel approach worthy of further consideration. However, deployment of the payload from inside the EOS payload bay to a position outside and adjacent to the vehicle body does not appear to provide sufficient advantages to offset the structural weight penalty that appears to be associated with this concept. The structural weight penalty occurs because the payload bay door is required to support the tug/payload during launch and thus becomes a primary structural element; in the baseline EOS vehicle, the door is essentially a non-structural element. The EOS vehicle tentatively uses the inside surfaces of the payload bay doors for the thermal radiators. When used for the radiators, the doors would be opened during exoatmospheric flight so that heat could be dissipated from the radiator surface. If the payload were attached to the payload bay doors, then an alternative surface would be required for the radiators. Alternative locations would be difficult to find since the majority of the external surface of the EOS is comprised of shingles that are used for thermal protection purposes during re-entry and do not readily lend themselves for use as a radiator. A more detailed evaluation of this aspect of the design would be required if the payload bay door concept is actively considered as a future candidate.



It has been tentatively concluded from an evaluation of the various payload deployment/retrieval mechanism concepts considered that the teleoperator combined with, for example, a pivot-type mechanism offers a desirable combination for deployment/retrieval of the tug/payload and that the weight associated with the concept relative to other concepts is not excessive.

The ultimate selection of a deployment/retrieval mechanism requires a more detailed knowledge of the design and operational characteristics of the payload and payload mixes contemplated for use with the EOS/tug system.

#### IX. COMPARISON BETWEEN GROUND AND SPACE-BASING CONCEPTS

A comparison of the mission operational characteristics for a ground-based tug/payload vehicle operating in a ground-based and space-based mode (identified by the symbol GB in Figure 3), as shown in Figure 2, indicates several significant differences in the design requirements for the respective modes.

The launch configurations differ, as shown in Figures 1 and 2, in that an additional docking interface mechanism, that is, one on each end of the payload, is required for the TDRS payload operating in a space-based mode. The additional docking device is required to mate with the tug if orbital mating (Figure 2) is considered whereas the docking device on the other end is used to support the payload from the EOS vehicle docking mechanism during launch. The docking device used for supporting the payload during launch is also used to deploy the payload/tug combination if an alternative docking method is considered in which the tug is docked to the payload while the payload is still attached to the EOS.

The relative positions of the ground and space-based payload in the EOS payload bay are different for the respective launches (Figures 1 and 2). In the ground-based tug/payload arrangement, the payload is located in the aft end of the EOS payload bay since it is attached to the tug; in the space-based arrangement, the payload, since it is launched separately, is attached directly to the EOS docking device that is located adjacent to the forward bulkhead in the MDAC baseline. The power, sensing, command, etc. interface disconnects would therefore be in different locations in the EOS vehicle for the respective basing modes.

An evaluation of the ground-based payload electrical, signal and sensing connector requirements suggests that only a single connector for mating with the tug is required. Conversely, in the space-based mode involving separate payload and tug launches, two connectors for electrical, signal and sensing functions are required in the EOS for mating with the tug and payload. It may be possible through careful design to achieve interchangeable interfaces by standardizing the payload interfaces. A more detailed analysis is required to adequately identify the differences in interface characteristics and to evaluate the various alternatives associated with the ground and space-based payloads.

The MDAC EOS payload structural supports (Figure 12) which were used as baseline for this study were defined specifically for the integral tug/payload ground-based launch mode. The design of the structural supports associated with the ground and space-based tug/payload will differ due to differences in the relative locations of the ground and space-based payloads (Figures 1 and 2) with respect to the EOS baseline payload mounting support points shown in Figures 12 and 13. The aft structural payload attachment, also shown in Figure 13, is part of a typical support concept developed specifically for the ground-based tug/payload arrangement. The structure was located as shown to support the tug but is not suitably located for supporting the space-based tug and payload when launched separately. An analysis of the structural support requirements for a variety of payloads should be conducted to determine if the support locations can be standardized.

One of the alternative tug/payload orbital mating concepts, identified in Figure 2, shows the space-based tug being docked to the payload while the payload is still attached to the EOS. This mode of docking differs from the docking method postulated for the ground-based tug and payload in Figure 1. The actual docking and attachment of the payload to the tug while the payload is docked to the EOS may impose more severe docking loading conditions than for the orbital mode of docking identified for the ground-based tug/payload (TDRS) vehicle due to differences in the respective mass relationships since it is assumed that the closing velocities, and the alignment and shock absorbing characteristics associated with both docking modes, are similar. A more detailed analysis is required to determine whether the advantages associated with using the hard docking mode of operation compensates for the additional structural requirements that may be imposed on the tug.

## X. IMPACT OF EXPANDED STRATEGIES ON GROUND-BASED VEHICLE SYSTEM

From a review of the various alternative mission strategies outlined in Figure 3, several differences between the operational mode of a ground-based tug/payload (GB Figure 3) operating in a ground-based mode and, for example, a ground-based tug/payload operating in a space-based mode can be found. A comparison of strategies (Figures 3 and 4), listed as GB-X (ground-based extended mission design), GB/SB (both ground-based and space-based design), SB (space-based), and SB/OPD (space-based with orbiting propellant depot), was made to identify some of the requirements for achieving an extended mission capability and other operational requirements associated with the expanded strategies. A discussion of the more obvious differences are conducted under separate headings below.

### A. Extended Mission Capability

The space-based tug, with extended mission capability (up to 1 year on-orbit duration) may be required to perform several different missions during this time and, since refurbishment after each mission is impractical, the design requirements for the various interfaces and disconnects would differ from those required for a similar ground-based vehicle. The disconnects would include interface connectors (power, equipment, sensing, and command and control signals, wire lines, etc.), fuel connections, cryogenic replenishment connectors for power systems, etc. Differences in the design requirements would result mainly from the longer on-orbit durations and increased component duty cycles in addition to the effects of wear and contamination, etc. that could contribute to possible connector malfunctioning. An extended mission capability requires longer storage of the cryogenic propellants which results in changes in the tank design, particularly, the tank insulation requirements.

### B. Operational Requirements

The operational requirements for a ground-based mode of operation as contrasted with space-basing differ significantly. The SP/OPD strategy listed in Figure 3 indicates that the tug would be refueled from an orbital propellant depot (OPD) as contrasted with being refueled on the ground. The refueling operation imposes an entirely different set of requirements to be

used in the design of the ground and space-based docking mechanisms and fuel transfer system. For example, the docking dynamics associated with the in-orbit docking of the tug and OPD will differ from the normal docking operation and will probably require that the tug be strengthened locally to accommodate higher loading conditions. The postulated concept of docking two tugs, identified in the GB (Figure 3) strategy for transferring payloads to higher energy orbits, may also significantly affect the docking mechanism, the design of the tug local structure in the vicinity of the docking mechanism, and the attachment design requirements.

### C. General Comments

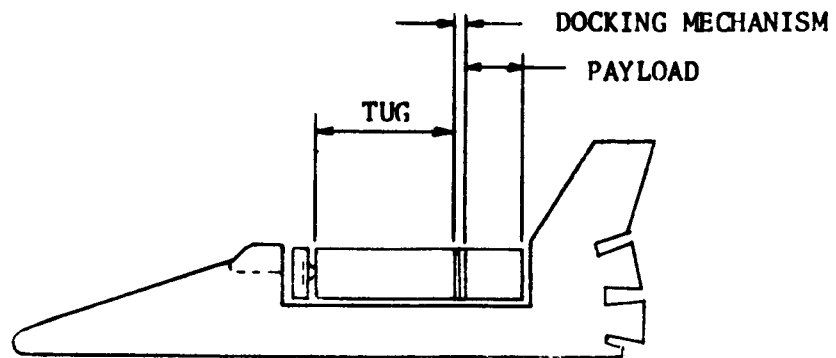
An in-depth comparative analysis of the space-based strategies, shown in Figure 3 and similar ground-based strategies, would be required to identify many of the changes in the tug design that result from differences in the various strategies. For instance, the tank insulation requirements will probably change due to the extended mission requirements and the skin thicknesses may change locally due to the higher loading conditions resulting from different docking requirements. Differences in the micrometeorite puncture criteria resulting from longer on-orbit stay times will also increase the outer tank skin thicknesses. The majority of the interface connections - dump valves, refueling devices, etc. - would also have different design characteristics due primarily to the higher duty cycles and longer on-orbit storage requirements.

One of the more significant items required for the space-based vehicle may include the requirement for a maneuverable propellant probe. The probe would be a part of the tug equipment and would be used to connect with an Orbital Propellant Depot (OPD) for refueling purposes in place of a hard docking device. Also, the tug may incorporate a mechanical grappling device to retrieve payloads not equipped with a universal docking device. In addition to devices required for the possible removal and replacement of specific components, devices for accomplishing possible space rescue missions may also be included.

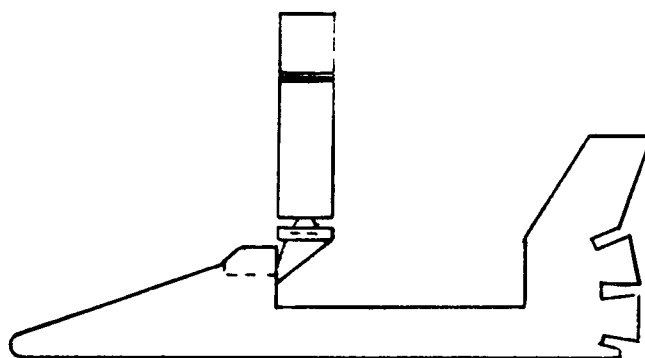
## XI. CONCLUSIONS

The selection of a payload deployment/retrieval mechanism is dependent on the configurational characteristics of the EOS payload(s). Several significant selection parameters have been defined for use when selecting a deployment/retrieval mechanism. Selection of a specific concept as the best overall is difficult to accomplish at this time since the payload design data and operational characteristics are not known in sufficient detail. However, if the details of the various EOS payloads and their deployment/retrieval characteristics are defined before finalization of the design of the EOS payload bay compartment, deployment/retrieval mechanism concepts can be identified that will satisfy the major requirements of the system.

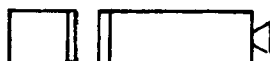
A comparison of the mission operational characteristics for a ground-based tug/payload vehicle and a ground-based vehicle operating in a space-based mode indicated several significant differences in the design requirements for the respective vehicles. The launch configurations differ in that an additional docking interface mechanism is required for the TDRS payload operating in a space-based mode. The relative positions of the ground and space-based payloads in the EOS payload bay for the respective launches are also different. In the ground-based tug/payload arrangement, the payload is located in the aft end of the EOS payload bay since it is attached to the tug; in the space-based arrangement, the payload, since it is launched separately, is attached directly to the EOS docking device that is located adjacent to the forward bulkhead in the MDAC baseline. The space-based tug, with extended mission capability (up to 1 year on-orbit duration) may be required to perform several different missions during this time and, since refurbishment after each mission is impractical, the design requirements for the various interfaces and disconnects differ from those required for a similar ground-based vehicle. These disconnects include interface connectors (power, equipment sensing, command and control signals, wire lines, etc.), fuel connections, possible requirement for cryogenic power systems, replenishment connectors, etc. The differences in the design requirements would result mainly from the longer on-orbit durations and associated component duty cycle requirements.



LAUNCH CONFIGURATION



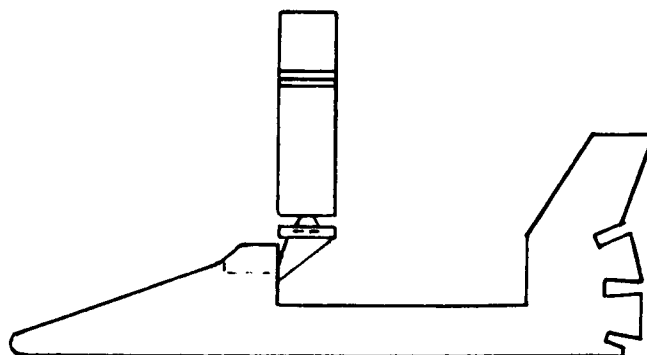
TUG/PAYLOAD DEPLOYED POSITION



SYNCHRONOUS ALTITUDE TUG/PAYLOAD SEPARATION

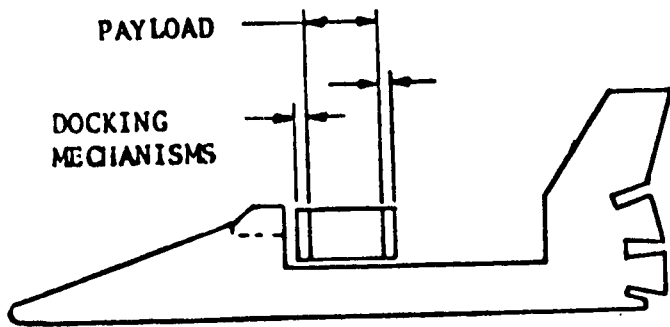


SYNCHRONOUS ALTITUDE PAYLOAD RETRIEVAL

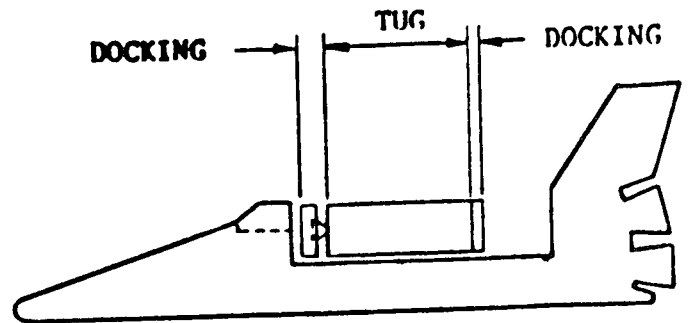


EOS TUG/PAYLOAD RETRIEVAL

FIGURE 1 GROUND-BASED STRATEGY

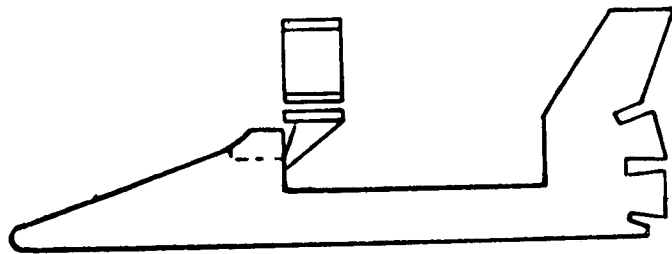


A1

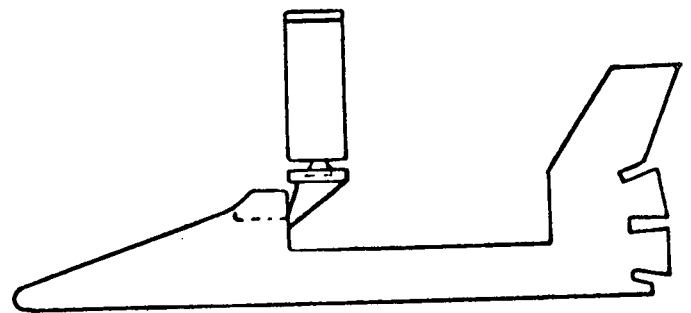


B1

### INDEPENDENT LAUNCH CONFIGURATIONS

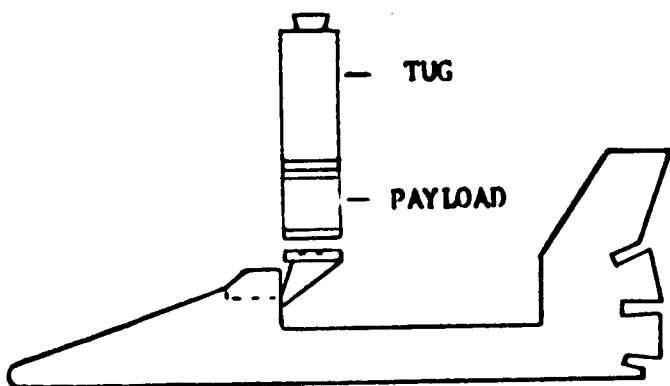


A2

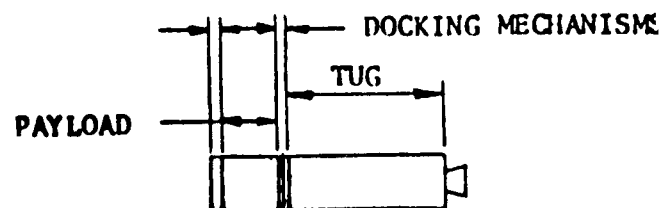


B2

### INDEPENDENT PAYLOAD AND TUG DEPLOYED POSITIONS



A3



IN-ORBIT MATING

B3

### TUG/PAYLOAD ORBITAL MATING ALTERNATIVES

**FIGURE 2 SPACE-BASED STRATEGY**

## SPACE BASING ANALYSIS

### REPRESENTATIVE SPACE-BASING STRATEGIES

- **[GB]** GROUND-BASED DESIGN AS IS
  - / SPACE-BASED CAPABILITY LIMITED TO WAITING ON ORBIT FOR ARRIVAL OF PAYLOAD OR SECOND TUG FOR TANDEM OPERATIONS
- **[GB-X]** GROUND-BASED DESIGN WITH EXTENDED MISSION DURATION CAPABILITY
  - / SPACE-BASED CAPABILITY SIMILAR TO GB EXCEPT THAT LATE ARRIVAL OF SECOND SHUTTLE FLIGHT DOES NOT COMPROMISE TOTAL MISSION
  - / PROVIDES ENHANCED SORTIE CAPABILITY
- **[GB/SB]** DESIGN WHICH SATISFIES BOTH GROUND- AND SPACE-BASED OPERATIONAL REQUIREMENTS
  - / ONE TUG DESIGN USED FOR BOTH OPERATIONAL MODES
- **[SB]** DESIGN BASED SOLELY ON SPACE-BASED OPERATIONAL REQUIREMENTS
  - / DESIGN CAN USE TOTAL VOLUME OF SHUTTLE PAYLOAD BAY
- **[SB/OPD]** SPACE-BASED DESIGN OPERATING IN CONJUNCTION WITH ORBITING PROPELLANT DEPOT
  - / OPD PROVIDES GARAGE BETWEEN TUG MISSIONS



**SPACE BASING ANALYSIS  
VEHICLE SYSTEM IMPLICATIONS**

VEHICLE SYSTEM PARAMETER	SPACE-BASING STRATEGY				
	GB	GB-X	GB/SB	SB	SB/OPD
STRUCTURE FACTOR	LOW	LOW	HIGH	HIGH	LOW
SIZE, % PAYLOAD BAY VOL.	~50%	~50%	~50%	~100%	~100%
PACKAGING DENSITY	HIGH	HIGH	VERY HIGH	MODERATE	LOW
MISSION DURATION	~2 WK	~2 MO	~1 YR	~1 YR	~1 YR
STORAGE MODE	ACTIVE	QUIESCENT	QUIESCENT	QUIESCENT	DORMANT
METEOROID PROTECTION	LIGHT	~LIGHT	HEAVY	HEAVY	LIGHT
ON-ORBIT PROPELLANT TRANSFER	NO	TOPPING	LOAD	LOAD	LOAD/ UNLOAD
ON-ORBIT GUID. PROGRAM.	NO	UPDATE	YES	YES	YES
PAYLOAD HANDLING	YES	YES	YES	YES	YES
CHECKOUT/DIAGNOSIS	NO	HEALTH ONLY	YES	YES	YES
ON-ORBIT MAINTENANCE (LINE ONLY)	NO	NO	YES	YES	YES
MAJOR OVERHAUL	GROUND	GROUND	GROUND	GROUND	GROUND
THERMAL INSULATION OPERATING ENVIRON.	ATMOS & VACUUM	ATMOS & VACUUM	ATMOS & VACUUM	VACUUM ONLY	VACUUM ONLY
NUMBER OF REUSES BETWEEN OVERHAUL	~10	~10	>10	>10	>10

FIGURE 4

**SPACE BASING ANALYSIS**  
**PROGRAMMATIC IMPLICATIONS**

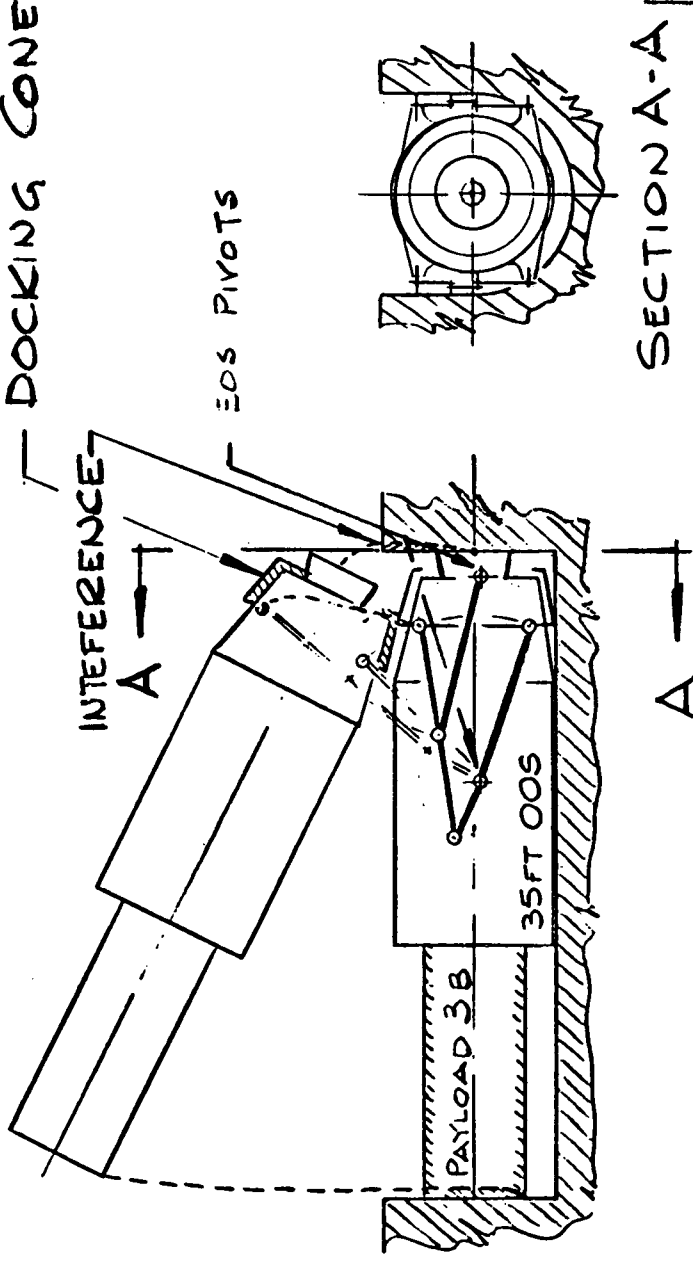
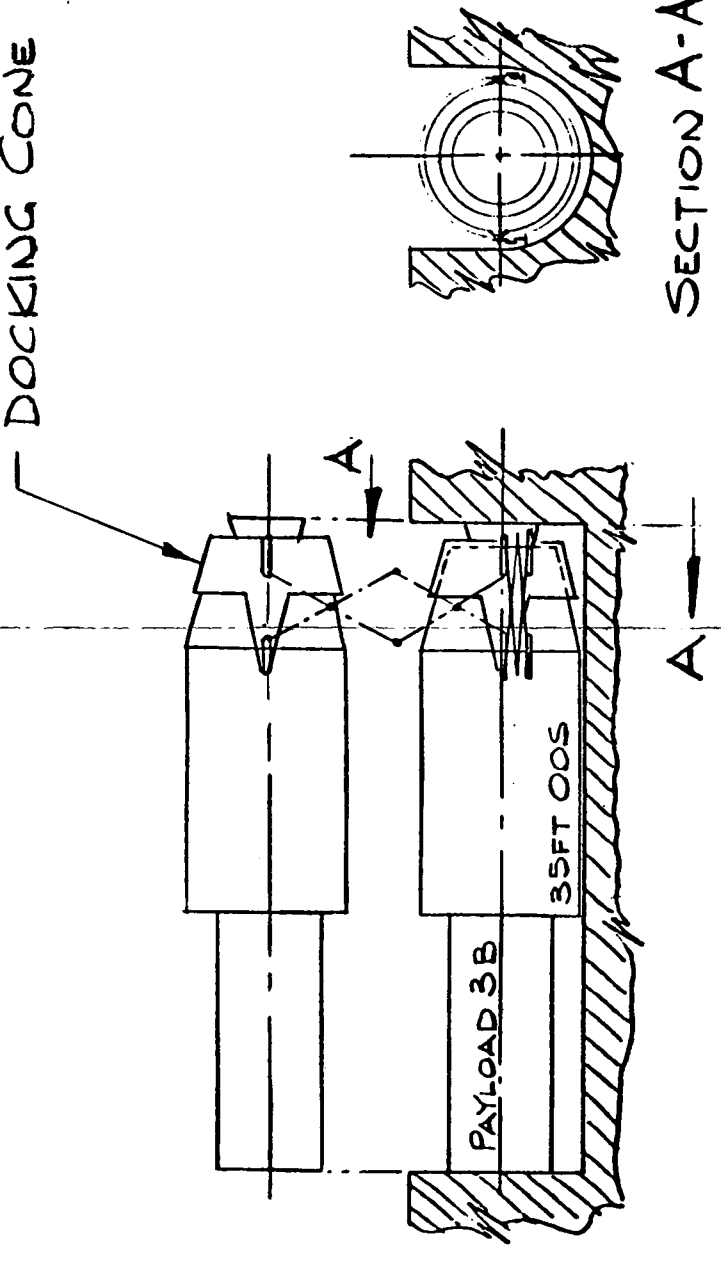
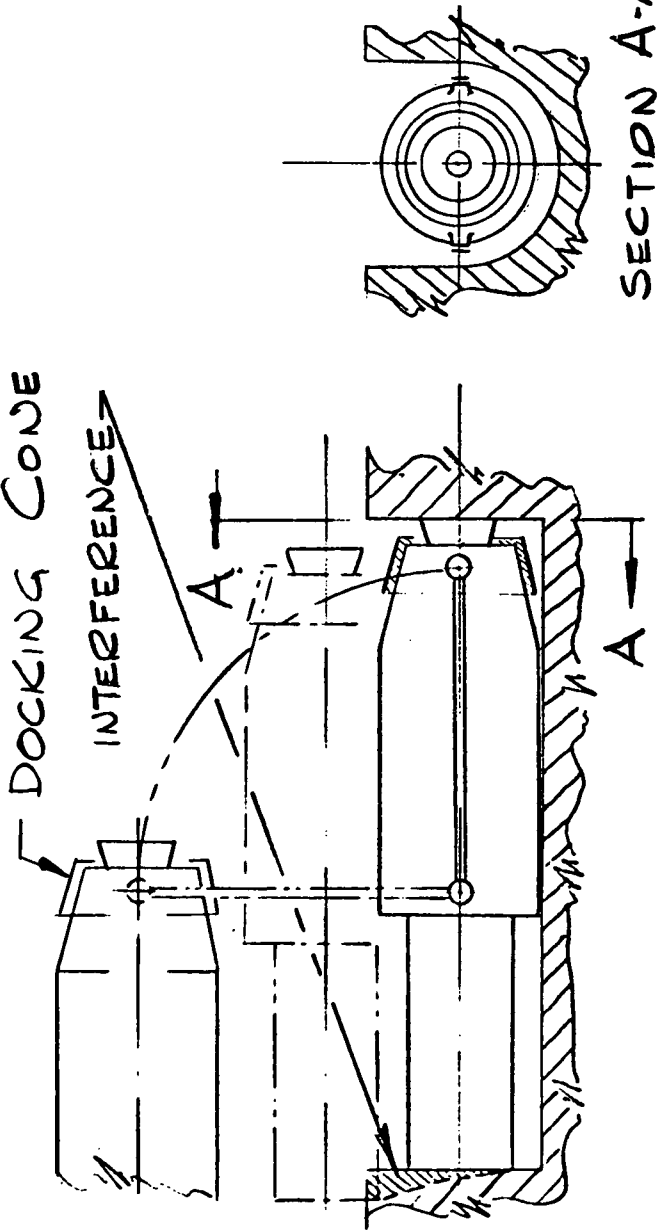
PROGRAMMATIC IMPLICATIONS	SPACE-BASING STRATEGY				
	GB	GB-X	GB/SB	SB	SB/OPD
USE OF SURPLUS PROPELLANTS DELIVERED TO HIGH TRAFFIC ORBIT PLANES	NONE	SLIGHT	SUB-STANTIAL	SUB-STANTIAL	LARGEST
REDUCTION IN ORBITER FLEET SIZE - NO WAITING IN PARKING ORBIT	NONE	SLIGHT	MAXIMUM	MAXIMUM	MAXIMUM
LUNAR/PLANETARY MISSION POTENTIAL	NO	NO	YES	YES	YES
CISLUNAR SHUTTLE POTENTIAL	NO	NO	NO	YES	YES
USE AS EXCESS PROPELLANT BUILDUP DEPOT	NO	NO	LIMITED	MAJOR	MAXIMUM
SORTIE CAPABILITY	VERY LIMITED	LIMITED	YES	YES	YES
PERFORMANCE, LB PAYLOAD/LB PROPELLANT	HIGHEST	HIGH	LOWEST	LOW	HIGH
PAYLOAD CAPABILITY / SINGLE STAGE FLIGHT	MEDIUM	MEDIUM	LOW	HIGH	HIGHEST
SENSITIVITY TO REDUCTION IN SHUTTLE P/L CAPABILITY	HIGH	HIGH	LOW	LOW	LOW
SENSITIVITY TO SHUTTLE LAUNCH ABORT/DIVERSION	HIGH	REDUCED	LOW	LOW	LOW
TECHNOLOGY ADVANCE REQUIRED	NONE	MINOR	SIGNIFICANT	SIGNIFICANT	SIGNIFICANT
NUMBER OF TUG CONFIGURATIONS REQUIRED	1	1	1	2	2

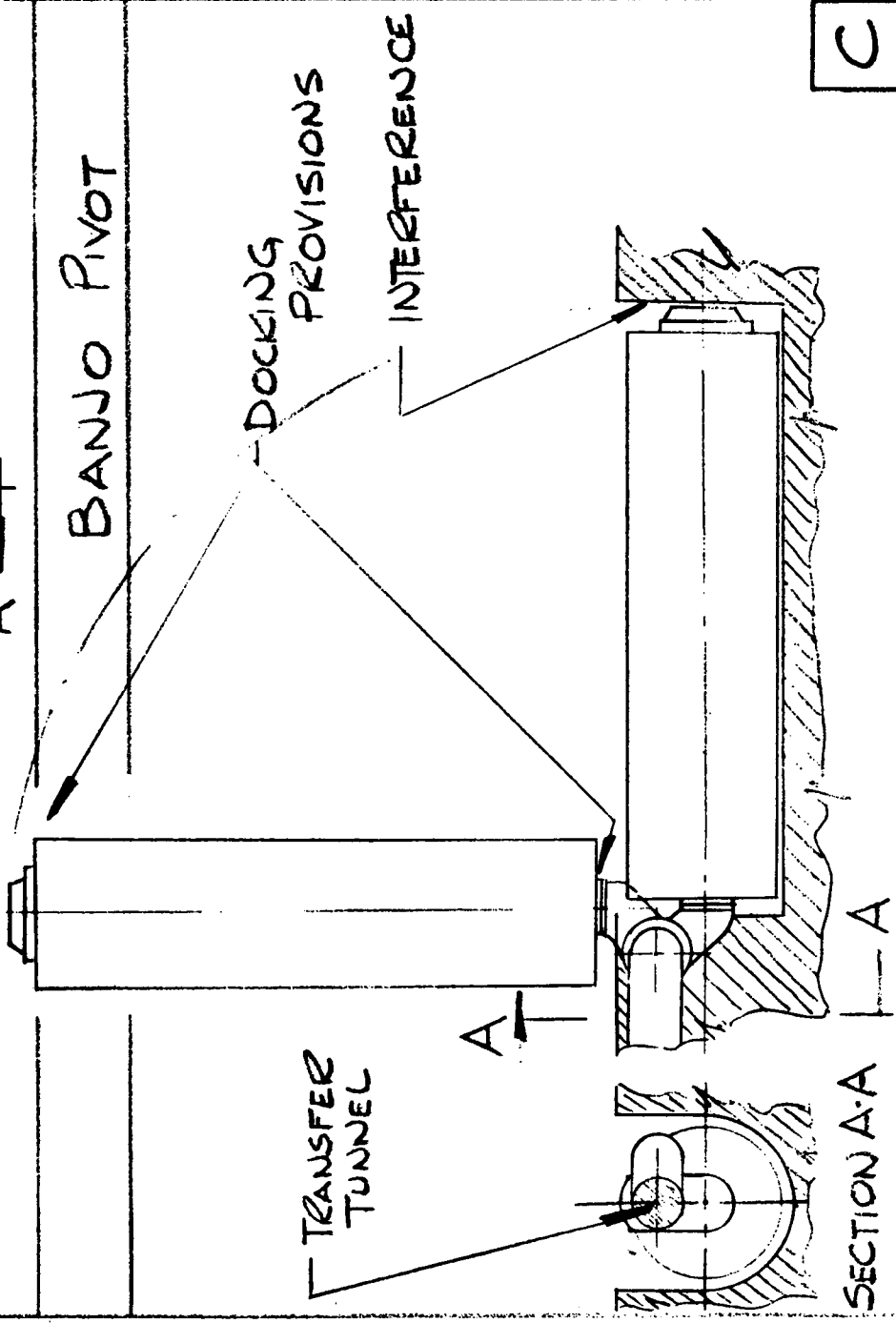
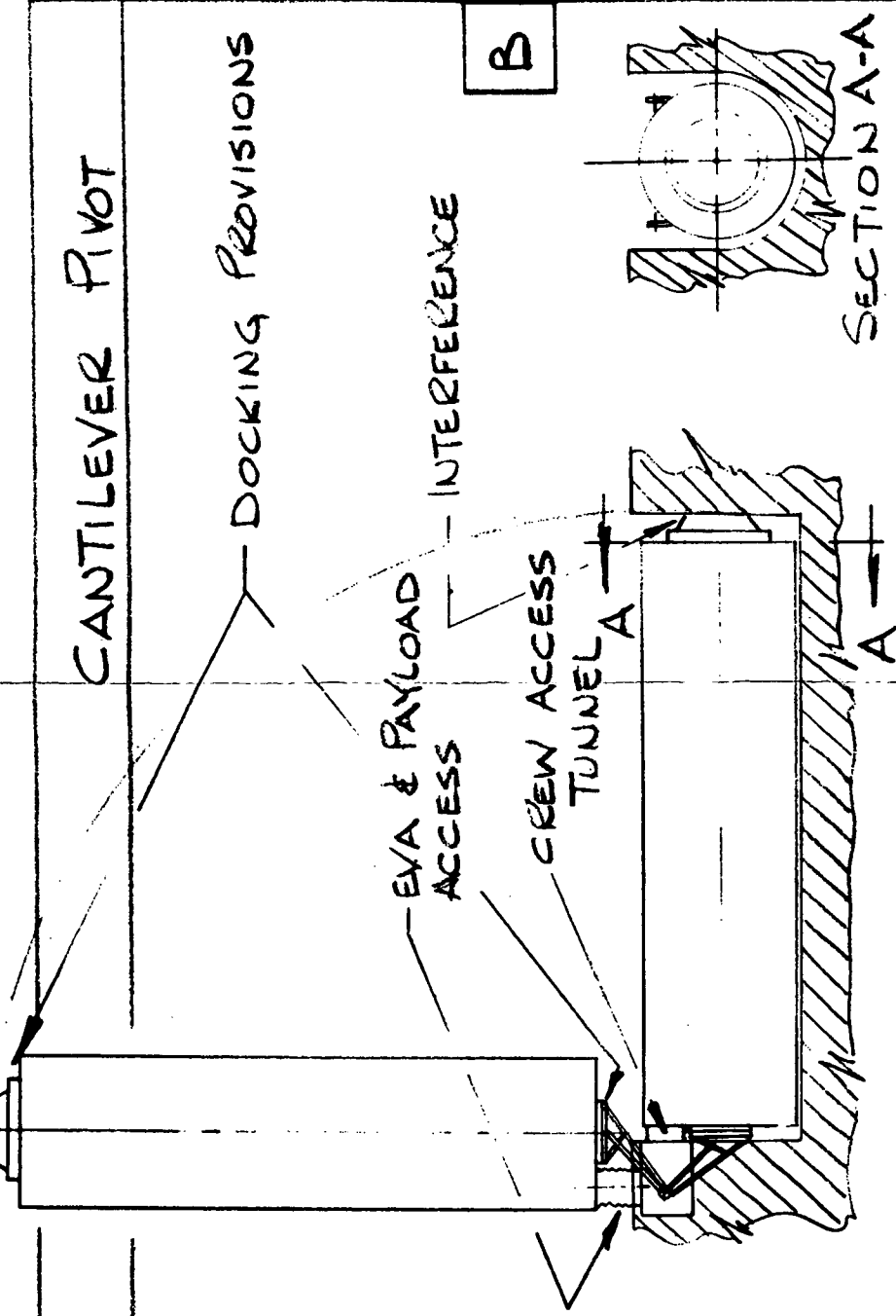
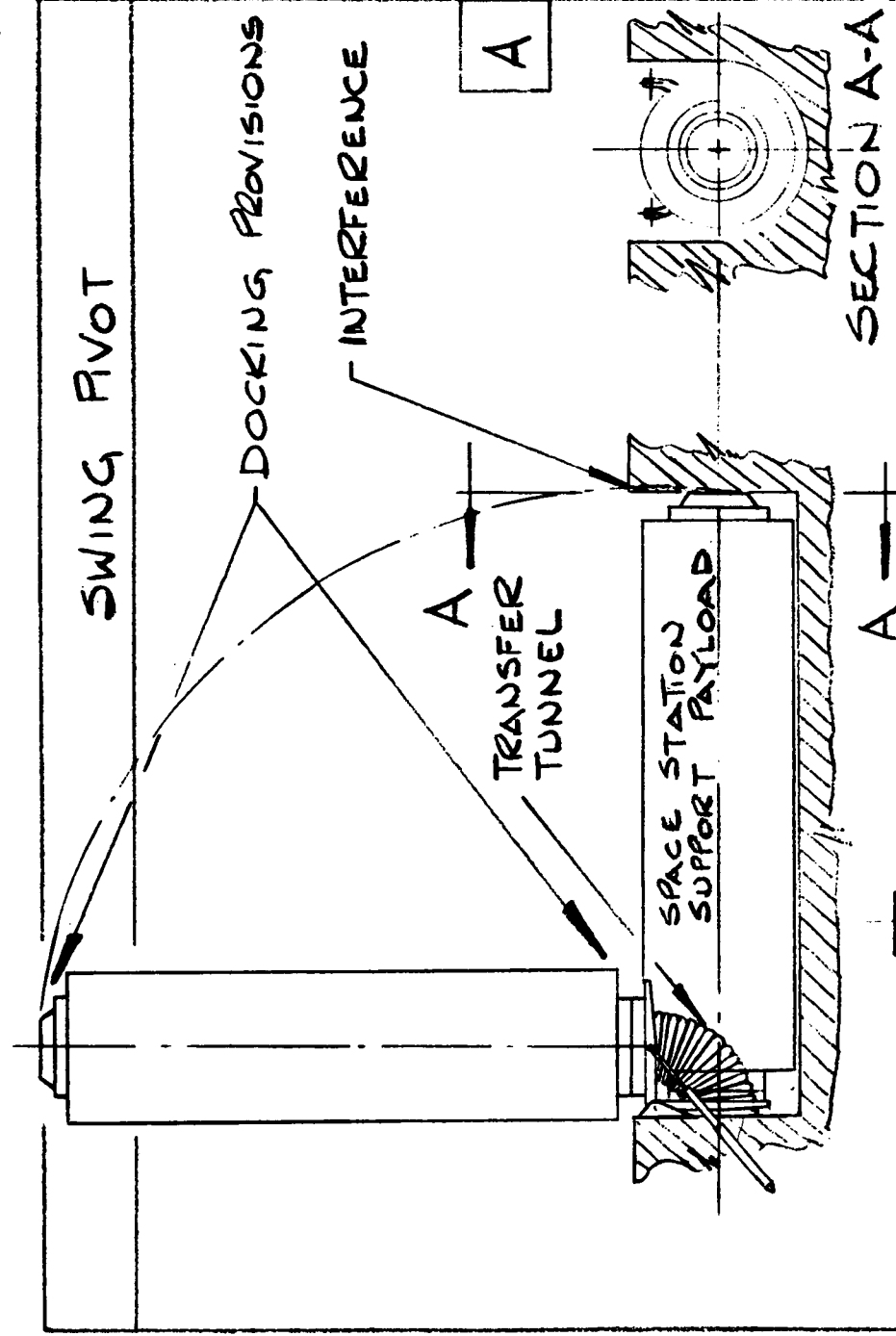
FIGURE 5

FOLDOUT FRAME)

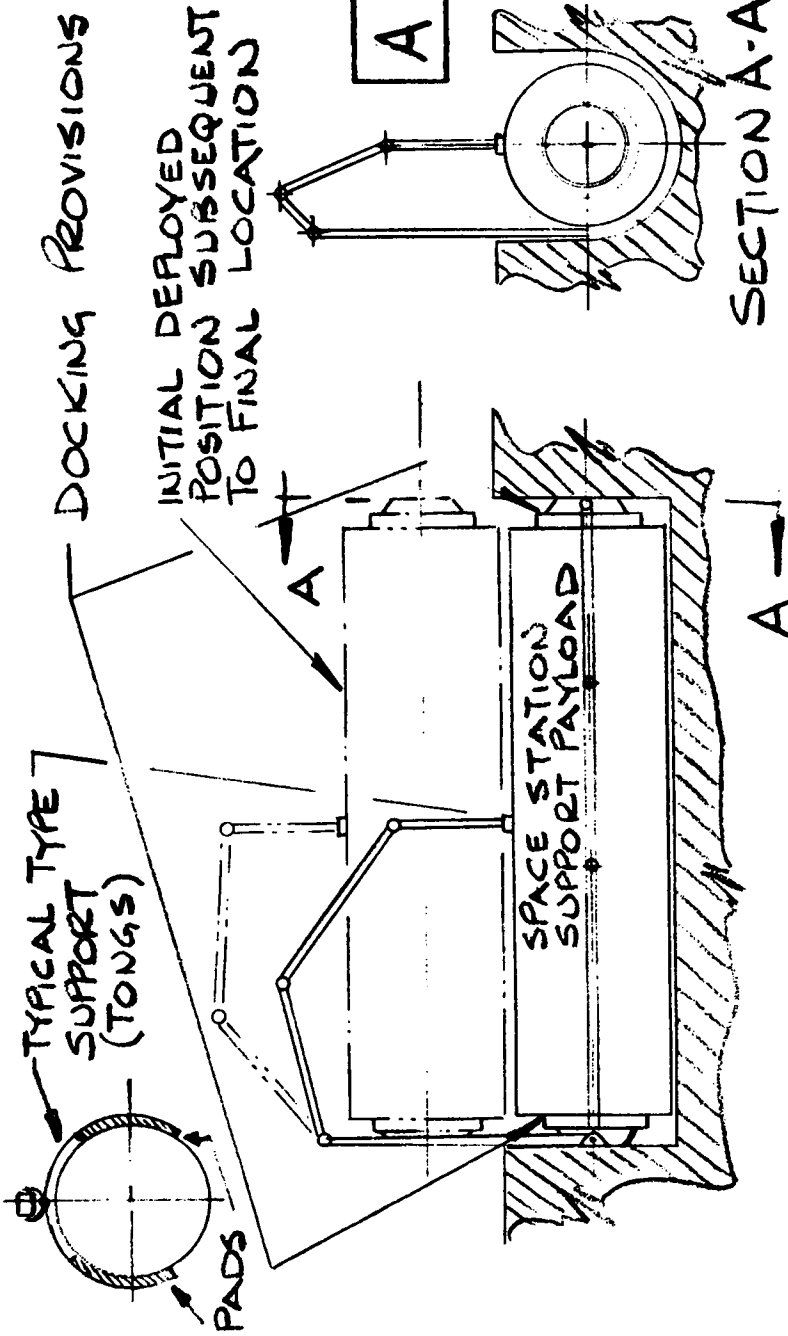
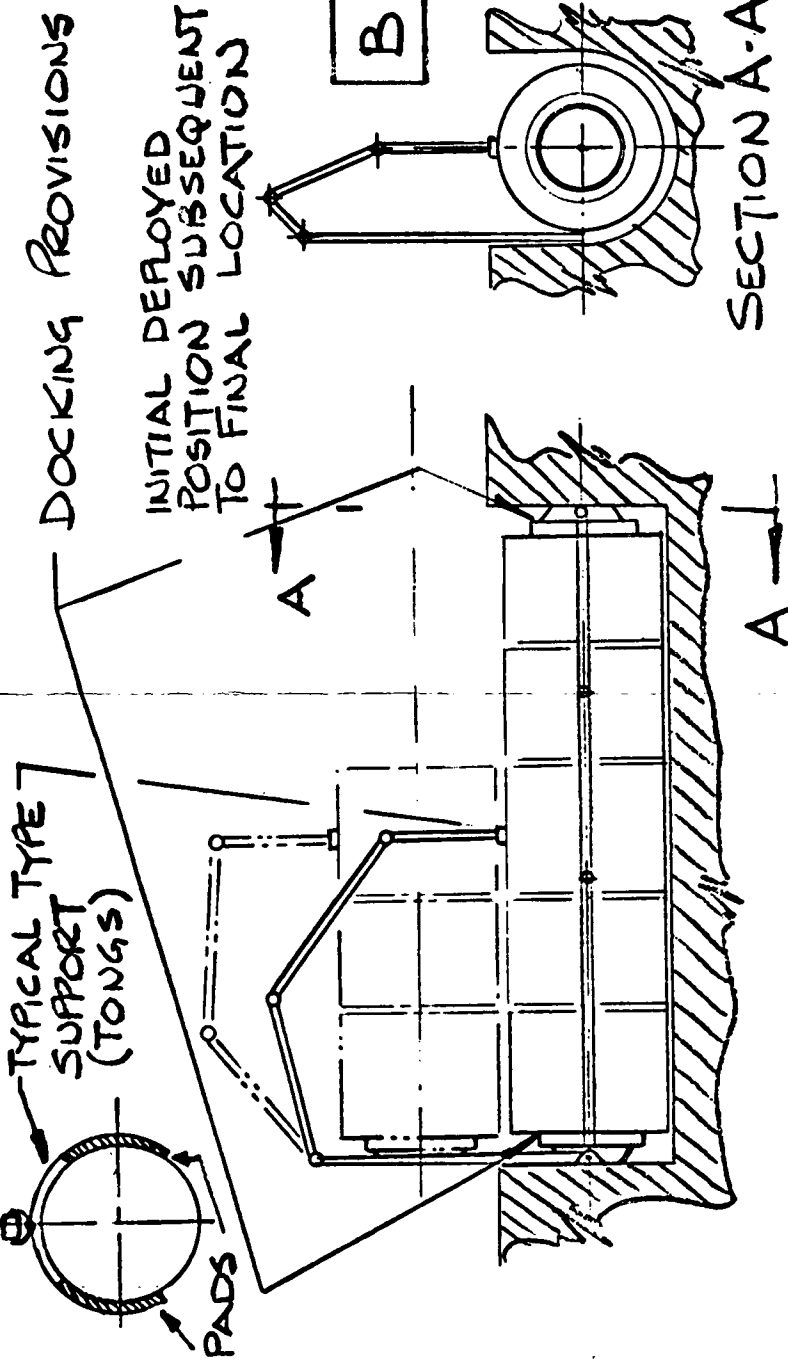
LINKAGE DEPLOYMENT/RETRIEVAL CONCEPTS

FOLDOUT FRAME ~

DUAL 4-BAR LINKAGE	DUAL SCISSOR LINK
 <p>DOCKING CONE</p> <p>INTERFERENCE</p> <p>EOS PIVOTS</p> <p>PAYLOAD 3B</p> <p>35FT OOS</p> <p>SECTION A-A</p>	 <p>DOCKING CONE</p> <p>PAYLOAD 3B</p> <p>35FT OOS</p> <p>SECTION A-A</p>
DUAL SWING LINK	
 <p>DOCKING CONE</p> <p>INTERFERENCE</p> <p>SECTION A-A</p>	



TELEOPERATOR DEPLOYMENT / RETRIEVAL CONCEPTS

SIMPLE CRANE (SINGLE PAYLOAD)	SIMPLE CRANE (MULTIPLE PAYLOADS)
 <p>TYPICAL TYPE SUPPORT (TONGS)</p> <p>PADS</p> <p>SPACE STATION SUPPORT PAYLOAD</p> <p>INITIAL DEPLOYED POSITION SUBSEQUENT TO FINAL LOCATION</p> <p>SECTION A-A</p>	 <p>TYPICAL TYPE SUPPORT (TONGS)</p> <p>PADS</p> <p>INITIAL DEPLOYED POSITION SUBSEQUENT TO FINAL LOCATION</p> <p>SECTION A-A</p>

# PAYLOAD BAY DOOR DEPLOYMENT / RETRIEVAL CONCEPTS

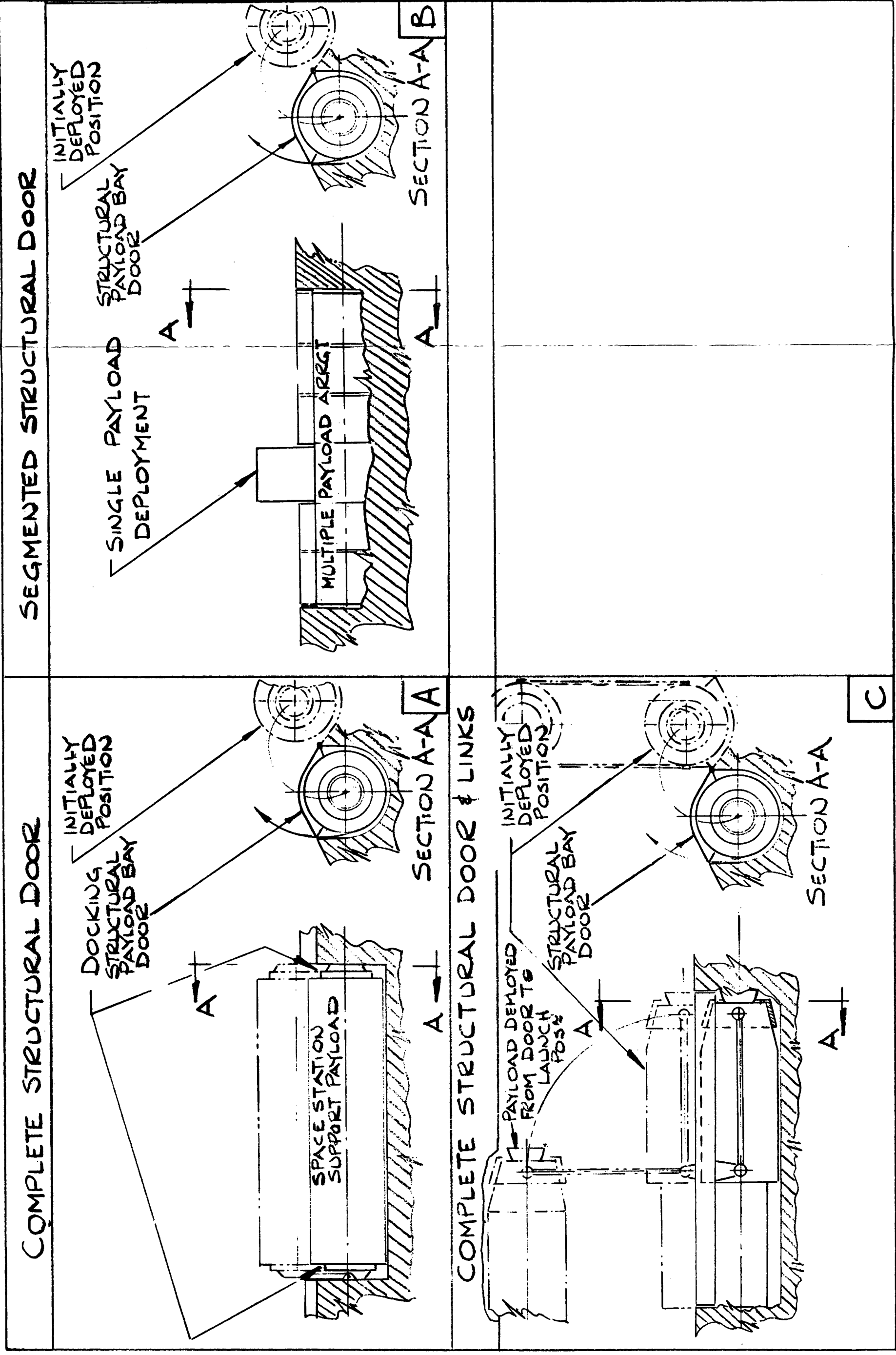


FIGURE 9

COMBINED DEPLOYMENT / RETRIEVAL CONCEPTS

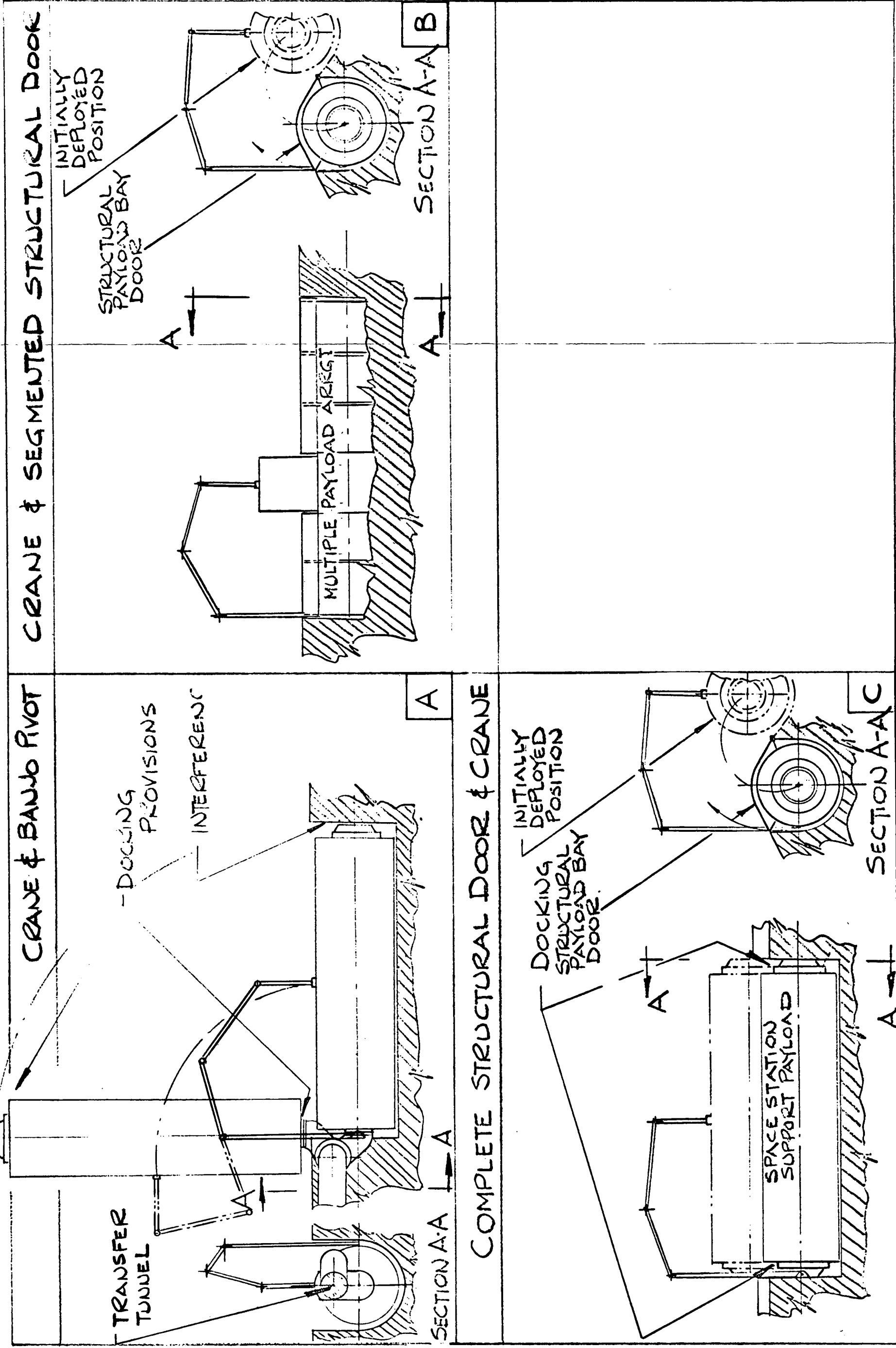


FIGURE 10

# DEPLOYMENT/RETRIEVAL MECHANISM SELECTION GUIDE

MECHANISM CONCEPT	SYSTEM WEIGHT IMPACT	OPERATIONAL RELIABILITY	POWER REQUIREMENTS	THERMAL DISTORTION EFFECTS	MECHANISM COMPLEXITY	ADAPTABILITY TO PAYLOAD MIX	OOS IMPACT	MECHANISM CHECK-OUT AND ADJUSTMENT ASSESSIBILITY
LINKAGES (FIG. 6)	A	3			5	2		5
	B	3			5	2		5
	C	2			4	2		4
FORWARD PIVOT (FIG. 7)	A	4			2	2		3
	B	3			1	2		2
	C	4			2	2		3
TELE- OPERATOR (FIG. 8)	A	1			4	1		2
	B	1			4	1		2
PAYLOAD BAY DOOR (FIG. 9)	A	6			2	3		1
	B	8			4	3		1
	C	7			3	3		1
COMBINED CONCEPTS (FIG.10)	A	5			4	3		2
	B	9			5	4		2
	C	8			3	3		2

FIGURE 11

NOTE:

The numerical values indicate rankings within each listed parameter only and may not be used for comparison purposes between parameters.



ENCLOSURE 2

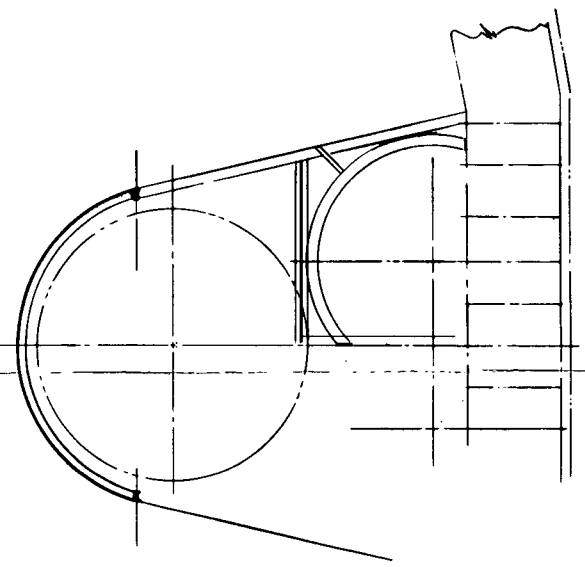


FIGURE 12

# EOS PAYLOAD BAY ARRANGEMENT

PAYLOAD BAY COMPARTMENT 65.75FT (REF)

A

PAYLOAD DEPLOYED POSITION

EOS ORBITER PAYLOAD  
STRUCTURAL SUPPORT LOCATIONS  
(AS SHOWN IN FIG 1)

OOS/TDRS PAYLOAD  
PAYLOAD ENVELOPE  
(60FT LONG 15FT DIA)

FWD

ADAPTER STRUCTURE  
MDAC DOCKING MECHANISM

5.0 REF

A

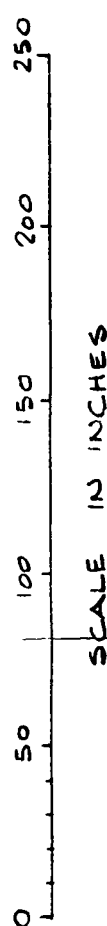
PAYLOAD & DOCKING  
MECHANISM  
INTERFACE

1076  
(REF)

EOS ORBITER STRUCT.

3.0 REF

APPROXIMATE  
PAYLOAD CG LOCATION  
OOS/TDRS INTERFACE



TYPICAL TUG-TO-EOS

DOCKING ARRANGEMENT

FIGURE 13

SECTION A-A  
SHOWING FORWARD PAYLOAD SUPPORT